A critical review of building environmental assessment tools

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Abstract

Since the field of environmental assessment tools for buildings is vast, the aim of this study is to clarify that field by analysing and categorising existing tools. The differences between the tools are discussed and the current situation within the tools is critically analysed. However, the comparison of the tools is difficult, if not impossible. For example, the tools are designed for assessing different types of buildings, and they emphasise different phases of the life cycle. In addition to environmental aspects, sustainable building includes economic and social aspects. The shift from green building to sustainable building and the future requirements are challenging for building environmental assessment tools. Furthermore, the benefits of using the tools should be analysed — how the tools and their results have affected decision making?

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1. Introduction

Industrial sectors, including the building sector, started to recognize the impact of their activities on the environment in the 1990s. Significant changes were needed to mitigate the environmental impact of building sector. The building sector had to focus on how buildings were designed, built and operated. One of the drivers was public policy, and another was the growing market demand for environmentally sound products and services. When aiming to reduce environmental impacts, a yardstick for measuring environmental performance was needed (Crawley and Aho, 1999). The specific definition of the term “building performance” is complex, since different actors in the building sector have differing interests and requirements (Cole, 1998). Economic performance, for example, interests investors, whereas the tenants are more interested in health and comfort related issues.

Separate environmental indicators were developed for the needs of relevant interest groups. However, the first real attempt to “establish comprehensive means of simultaneously assessing a broad range of environmental considerations in buildings” was the Building Research Establishment Environmental Assessment Method (BREEAM) (Crawley and Aho, 1999). BREEAM, the first commercially available environmental assessment tool for buildings, was established in 1990 in the UK (Grace, 2000). Since then many different tools have been launched around the world (e.g. DOE, 1996/2006; IEA Annex 31, 2001; Reijnders and van Roekel, 1999).

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The development of different tools in the building sector has been active. Different organisations and research groups have contributed new knowledge through experience. The tools have gained considerable success during the past years. However, the success of the assessment tools has dwarfed all other mechanisms for instilling environmental awareness (Cole, 2005). The discussion on the sustainability in the building sector has gained international forum. Green Building Challenge (GBC), for example, has organised several major international conferences, which have substantially contributed to the development of sustainable building. Currently, the focus is expanding towards developing countries.

Furthermore, the International Organization for Standardization (ISO) has been active in defining standardised requirements for the environmental assessment of buildings. ISO Technical Committee (TC) 59 “Building construction” and its Subcommittee (SC) 17 “Sustainability in building construction” have published two technical specifications:


The European Committee for Standardization (CEN), and CEN/TC “Sustainability of construction work” develops voluntary horizontal standardised methods for the assessment of the sustainability aspects of new and existing construction works and standards for the environmental product declaration (EPD) of construction products (CEN, 2005). Technical Committee (TC) 350 has three working groups. The estimated dates for the working groups’ standards are also mentioned:

- WG 1 environmental performance of buildings
  - Framework for assessment of integrated building performance (under approval, 09/2007)
- WG 2 building life cycle description
  - Assessment of environmental performance of buildings — calculation methods (under development, 11/2008)
- WG 3 product level
most of the tools included in this study have been presented in the proceedings of international conferences (e.g. Grace, 2000; Hansen, 2005; Petersen, 2002). Additional information had to be collected from the homepages of the tools.

The building stock is different on different continents. In Europe, for example, the building stock is old, and therefore the maintenance and refurbishment of the existing buildings are critical issues for sustainable building construction. The situation is different in North America. There the urban areas grow rapidly, but the maintenance and refurbishment also need attention (Kohler and Moffatt, 2003). Considering the climate, the western culture of building and living, and the moderate uniform of new building, this study focus on the environmental assessment tools developed in Europe and North America.

The number of the tools included in the study had to be controlled; otherwise the study would have been too wide and complex. None of the tools have been tested for this study. The categorising and analysis of the tools is based on written material evaluated by the authors. In this study various references were used. Different references discuss issues differently and this may have had some influence on the results of this study. The possible influence on the results is small, however, because the tools are discussed as a group rather than as individuals.

TEAM™ is the only tool in this study that is not specifically for the environmental assessment of buildings. It is a professional LCA-tool, for evaluating the life cycle, environmental and cost profiles of products and technologies, including buildings. TEAM™ is included in this study as an LCA-tool representative of a number of similar process-based LCA-tools, such as GaBi (Germany) and SimaPro (Netherlands).

1.3. Content of the study

In the first section, the Introduction, the research area is briefly introduced, the aim and the definitions are stated, and the content of the study is listed. In the second section, the building environmental assessment tools selected for this study are presented. In the third section, the focus is on categorising the building environmental assessment tools. Firstly, the existing classification systems are introduced. Secondly, the tools are categorised by different characteristics; the assessed buildings, the users of the tools, the phases of the life cycle, the database, and the form used to present the results. Also, the uncertainties and the errors are discussed. In the fourth section, the Discussion, the current situation within the tools is analysed and the future of the tools is speculated. In the fifth section, the Conclusion, the results from this study are highlighted, and the topics for further research are discussed.

2. Existing building environmental assessment tools

The building environmental assessment tool and sustainability in building construction has become popular as a research area. There have been several international projects in the field: BEQUEST “Building Environmental Quality for Sustainability through Time” (BEQUEST), CRISP “A European Thematic Network on Construction and City Related Sustainability Indicators” (CRISP, 2004), IEA Annex 31 “Energy related Environmental Impact of Buildings” (IEA Annex 31, 2001), and PRESCO “European Thematic Network on Practical Recommendations for Sustainable Construction” (Peuportier and Putzeys, 2005). The Green Building Challenge (GBC) has been analysed by e.g. Cole (1999, 2001), Cole and Larsson (1999) and Kohler (1999). There are several articles about building environmental assessment methods (e.g. Cole, 2004; Cooper, 1999; Crawley and Aho, 1999). Building environmental assessment tools are compared in a few studies (e.g. Forsberg and von Malmborg, 2004; Todd et al., 2001), and the results of the tools are compared by e.g. Aotake et al. (2005) and Kawazu et al. (2005). Previously, building environmental assessment tools have been analysed more as individuals rather than as groups. Neither shared aspects and common features, nor differences have been emphasised in the studies. Weaknesses or limitations have not been pointed out very strongly. However, these issues are important for the development processes of the building environmental assessment tools. Also, they affect the standardisation work.

There is a growing number of environmental assessment tools developed for the building sector all over the world. This study focuses on European and North American building environmental assessment tools. There are sixteen tools included in this study (Table 1). Most of the building environmental assessment tools have been developed by research institutes. Almost all of the tools can be bought, BEES is the only freely available tool — it can be downloaded from the Internet. The prices of the tools vary to a great extent. Most of the tools have discounted prices for universities and educational purposes.
The building environmental assessment tools included in this study are used at a national level. In addition to this, seven of them are can be used globally; BEES, TEAM™, ATHENA™, BEAT, Envest 2, BREEAM and LEED®. After BEES version 3.0 was released in 2002, over 22,000 copies of it have been requested from more than 80 countries. The new version, BEES 4.0 was released in May 2007. ATHENA™ is mainly for North American markets. BEAT was originally designed for national use. Due to the big interest in the tool outside Denmark, BEAT is available in Danish and in English. Moreover, the user can, at the moment, choose the language used in the user interface from a list consisting of four different languages. Envest 2 is used in the UK and Ireland, but it could be used overseas if the data were edited. According to Grace (2000), BREEAM versions have been developed for Canada, Hong Kong and New Zealand. LEED® is used in the USA, Canada, Spain, China and India.

### 3. Categorising building environmental assessment tools

The field of building environmental assessment tools is vast. The tools have been developed by various institutes and for different purposes. The emerging role of the building environmental assessment tools encourages discussing the contents and framework of the different tools and also, the context. This discussion requires categorising the tools. There are two well-known classification systems for the environmental assessment tools. One was developed by the ATHENA Institute (Trusty, 2000), and the other by IEA Annex 31 (2001).

#### 3.1. ATHENA classification system

The ATHENA Institute has introduced a classification system “Assessment Tool Typology” (Trusty, 2000).
(referred to later as ATHENA classification) which has three levels:

- Level 1: product comparison tools and information sources  
  - BEES 3.0 and TEAM™
- Level 2: whole building design or decision support tools  
  - ATHENA™, BEAT 2002, BeCost, Eco-Quantum, Envest 2, EQUER, LEGEP® and PAPOOSE
- Level 3: whole building assessment frameworks or systems  
  - BREEAM, EcoEffect, EcoProfile, Environmental Status Model, ESCALE, and LEED®.

**BEAT (2002), BeCost, EQUER, Environmental Status Model, LEGEP® and PAPOOSE** were not mentioned in the ATHENA classification. In this research they have been classified based on the similarity with the other tools in the group. In addition to the three actual levels in the classification system, there is a category for supporting tools and techniques. Those are the systems that provide more general support for the various tools, or for the design process itself (Trusty, 2000). Baseline Green is an example of a supporting system, and is a tool for improving the environmental performance of buildings. To retain focus, supporting tools have not been included in this study.

### 3.2. IEA Annex 31 classification system

In the project IEA Annex 31 “Energy related environmental impact of buildings” the assessment tools are categorised into five classes (IEA Annex 31, 2001). Here, the classification system is combined with the ATHENA classification system:

1. Energy Modelling software
2. Environmental LCA Tools for Buildings and Building Stocks  
   - Level 1: BEES 3.0 and TEAM™
   - Level 2: ATHENA™, BEAT 2002, BeCost, Eco-Quantum, Envest 2, EQUER, LEGEP® and PAPOOSE
   - Level 3: EcoEffect and ESCALE
3. Environmental Assessment Frameworks and Rating Systems  
   - Level 3: BREEAM, EcoProfile, Environmental Status Model and LEED®
4. Environmental Guidelines or Checklists for Design and Management of Buildings
5. Environmental Product Declarations, Catalogues, Reference Information, Certifications and Labels.

Environmental Status Model was not mentioned in IEA Annex 31 (2001). It has been classified based on the similarity with the other tools. In this research, the focus is on the tools in the second and third category in the classification of IEA Annex 31. Two types of tools were distinguished in the IEA Annex project: Interactive software and Passive tools. The tools in the first and second category are Interactive tools, while the tools in the third, fourth and fifth category are Passive tools. Baldwin et al. (2000) say, Interactive software tools “provide calculation and evaluation methods which enable the user or decision maker to take a pro-active approach (to explore a range of options in an interactive way)”. Passive tools support decision making, they do not allow interaction with the user (IEA Annex 31, 2001; Baldwin et al., 2000).

In the ATHENA classification the focus is on the assessment tools. The tools are classified into different levels depending on where in the assessment process they are used, and for what purpose (Trusty, 2000). In addition to the assessment tools, the IEA Annex 31 includes energy modelling software, different environmental guidelines, checklists, product declarations and certifications into the classification system. Consequently, the field of classified tools is much wider in the IEA Annex 31 classification than in ATHENA classification. All of the tools classified in the ATHENA classification belong to the second or third category in the IEA Annex 31 classification.

Assessment tools are solutions for implementing evaluation methods and calculation. Often, the tools can be used in the design phase to help planning and support decision making. All thirteen tools included in this study are assessment tools, and three quarters of them can be used as planning tools (Levels 1 and 2 tools, and also EcoProfile and ESCALE from Level 3 tools). Most of the building environmental assessment tools are software programmes. However, the variety is large. The more evaluation and calculation included in the tool, the more dependent it is on information technology. IEA Annex 31 (2001) distinguished Interactive software and Passive tools, the former is more dependent on information technology than the latter. And in the ATHENA classification, Levels 1 and 2 tools are more dependent on information technology than Level 3 tools.

Currently, only some of the tools include analysis of life cycle cost (LCC). LCC is analysed at different levels of accuracy within the tools. Envest 2, for example,
provides whole life cost analysis, but BEAT calculates only the costs which differentiate the solutions under consideration. Naturally, LCC can be calculated with a separate tool, but combining the results with the results of the environmental assessment may be difficult and time consuming. Furthermore, sustainable building sets challenging requirements for the assessment tools — in addition to the environmental aspect, the economical and the social aspects need to be considered and included in the assessments.

3.3. Categorising tools by characteristics

ATHENA and IEA Annex 31 classification systems are both well-known. These classification systems emphasise the type and the framework of the assessment tools. In addition to these issues, the assessment tools can be categorised by their contents and characteristics. The ATHENA classification system was used as a supporting classification system in this study, because the focus of the ATHENA classification is on the assessment tools. According to Trusty (2000), the comparison should be within the classification level in the ATHENA classification; Level 1 tools should be compared only with other Level 1 tools and not with Level 2 or 3 tools, etc. By categorising the tools within the ATHENA classifications, it is possible to analyse the differences between the different Levels and furthermore, compare the tools within the Levels.

Different building environmental assessment tools have been developed for different purposes. The user groups of the tools vary to a great extent. The tools cover different phases of the building’s life cycle and take different environmental issues into account. The emerging role of the tools encourages discussing the tools more thoroughly, and this requires categorising the tools. By categorising the tools, the similarities and the differences of the tools can be seen, and this information can be utilised in the development of the tools. In the following sections, the building environmental assessment tools are categorised by

- the assessed building
- the users of the tools
- the phases of the life cycle
- the database of the tools
- the forms of the results used.

ATHENA classification system is used as a supporting classification system. In the following tables, the Level 1 tools are listed first, then Level 2 tools, and finally Level 3 tools.

3.3.1. Assessed buildings

Building environmental assessment tools can be used to assess existing building, new buildings, buildings under refurbishment, and also building products and components (Table 2). According to the ATHENA classification, Level 1 tools are mostly for product comparison and information resources, and Levels 2 and 3 tools are mostly for the environmental assessment of a whole building (Trusty, 2000).

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Assessed buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATHENA classification</td>
<td>Assessment tool</td>
</tr>
<tr>
<td>1</td>
<td>BEES 4.0</td>
</tr>
<tr>
<td>2</td>
<td>ATHENA™ TEAM™</td>
</tr>
<tr>
<td></td>
<td>BEAT 2002</td>
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<tr>
<td></td>
<td>BeCost</td>
</tr>
<tr>
<td></td>
<td>Eco-Quantum</td>
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<tr>
<td></td>
<td>Envest 2</td>
</tr>
<tr>
<td></td>
<td>EQUER</td>
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<td></td>
<td>LEGEP®</td>
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<tr>
<td></td>
<td>PAPOOSE</td>
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<tr>
<td>3</td>
<td>BREAM</td>
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<td></td>
<td>EcoEffect</td>
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<td>EcoProfile</td>
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<td>Environmental Status Model</td>
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<td></td>
<td>ESCALE</td>
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<tr>
<td></td>
<td>LEED®</td>
</tr>
</tbody>
</table>
Some of the tools can be used for product comparison and environmental assessment of a whole building; BEAT and EcoEffect, and also TEAM™ at some level. When TEAM™ is used for an assessment of a whole building, the building is decomposed into parts and elements. However, when the Level 1 tools are used in decision making for a whole building, they can be overloaded (Trusty, 2000). Even though TEAM™ can be used for an assessment of a whole building, it was not originally designed for the purpose. For this reason, TEAM™ is regarded as a tool for product comparison.

There are different types of buildings; residential buildings (single family or multi-unit), office buildings and other types of buildings. Most of the tools included in this study can be used to assess several types of buildings. However, some of the tools can only be used for certain types of buildings; for example, Envest 2 can only be used for the environmental assessment of office buildings. Some of the references used do not categorise different types of buildings. In these cases, it is impossible to know if the assessment tool is suitable for all types of buildings or not. In cases like this, the tool is marked to be used to assess “buildings” (Table 2).

Most of the tools included in this study can be used to assess existing buildings, new buildings and buildings under refurbishment, and also, different types of buildings; residential buildings, office buildings and other types of buildings. Is one building environmental assessment tool able to assess different kinds of buildings equally? Some tools, for example, BREEAM and LEED® have different versions for different building types. BREEAM has different versions for homes, multi-residents, schools, offices, prisons, and storages. Different versions have been developed to better recognise the special requirements of the buildings.

### 3.3.2. Users of tools

Building environmental assessment tools are developed for different purposes, for example for commercial and research use, and to support maintenance and decision making. This leads to wider user groups. In this study, the possible users of the tools have been identified as AEC professionals (architects, engineers, and constructors), producers of building products, investors/building owners, consultants, residents, facility managers, researchers and authorities. Different cultures and countries may define the roles of architects, engineers and constructors differently. For this reason, they are mentioned as one group — AEC professionals.

AEC professionals, consultants, researchers and authorities are the biggest user groups, and they are regarded as users of the Levels 1, 2 and 3 tools (Table 3). Producers of building materials are mostly regarded as users of the Levels 1 and 2 tools. Investors, residents and facility managers are mostly regarded as users of the Level 3 tools. Some of the tools, such as LEED®, EQUER, Eco-Quantum and EcoEffect have several user groups. At the same time e.g. ATHENA™, EcoProfile and Environmental Status Model and have a few user groups. Different tools define the user groups differently. Some of the tools name only the most important

| Table 3
| Users of the tools |
|-------------------|------------------|
| **ATHENA classification** | **Assessment tool** | **AEC professionals** | **Producers of building products** | **Investors, building owners** | **Consultants** | **Residents** | **Facilities managers** | **Researchers** | **Authorities** |
| 1 | BEES 4.0 | | | | | | | | |
| | TEAM™ | | | | | | | | |
| 2 | ATHENA™ | | | | | | | | |
| | BEAT 2002 | | | | | | | | |
| | BeCost | | | | | | | | |
| | Eco-Quantum | | | | | | | | |
| | Envest 2 | | | | | | | | |
| | EQUER | | | | | | | | |
| | LEP® | | | | | | | | |
| | PAPOOSE | | | | | | | | |
| 3 | BREEAM | | | | | | | | |
| | EcoEffect | | | | | | | | |
| | EcoProfile | | | | | | | | |
| | Environmental Status Model | | | | | | | | |
| | ESCALE | | | | | | | | |
| | LEED® | | | | | | | | |
user groups, “the actual users”, while the other tools name all the possible users of the tools. Considering this, it is very difficult, if not impossible, to distinguish the real users of the tools.

There is an obvious need for a user survey of the building environmental assessment tools. The factors influencing the choice of the tool need to be revealed; e.g. how the prices, availability, language, and coverage of the life cycle influence the decision. Even more important is to analyse how the tool and its results have affected decision making. User experience should be utilised in the development of the tools and also, the standards.

### 3.3.3. Phases of life cycle

The life cycle of a building, “from cradle to grave”, is divided into phases to enable the comparison of the building environmental assessment tools. In this study, the phases of the building’s life cycle are:

- Production of materials and components
- Construction
- Use/operation of the building
- Maintenance
- Demolition
- Disposal (recycling, landfill, incineration for energy recovery etc.).

The tools cover the phases of the building’s life cycle differently (Table 4). Half of the tools cover all the phases of the life cycle; four Level 2 tools, and two Level 3 tools. Some of the tools do not cover one or two phases of the life cycle. ATHENA™ does not cover the use/operation phase of building. TEAM™ and BREEMAM do not cover demolition, but they do cover disposal. However, an LCA process model for demolition can be created in an LCA-tool such as TEAM™. Two of the tools, EcoProfile and ESCALE, are more focused on the use and maintenance of buildings.

Even though the tools seem to cover the same phases of the building’s life cycle, they may cover the phases differently. One tool may use several criteria for a phase while another tool uses only a few criteria, still both tools are said to cover the phase in question. Furthermore, the tools may use the same criteria but different indicators to correspond these criteria. But which criteria are the most significant, which indicators correspond to these criteria best, and which alternative gives the user of the tool more significant information? (Haapio and Viitaniemi, 2007) These are vital questions. The comparison of the criteria and indicators from the user’s viewpoint is difficult, if not impossible. Values of different indicators vary depending on the user of the tools, for example, an architect may consider different indicators differently than an engineer. Consequently, the comparison of the results from environmental assessment is difficult.

### 3.3.4. Databases of tools

The building environmental assessment tools require a varying amount of data for their assessment. The use of databases varies among the building environmental assessment tools (Table 5). The comparison of the databases used by the tools is difficult. Several of the tools use well-known databases such as Oekoinventare (ETHZ), DEAM™ or ATHENA™. Some tools use a combination of different databases. Levels 1 and 2 tools use mostly one or a few well-known databases. Some of

<table>
<thead>
<tr>
<th>ATHENA classification</th>
<th>Assessment tool</th>
<th>Production</th>
<th>Construction</th>
<th>Use/operation</th>
<th>Maintenance</th>
<th>Demolition</th>
<th>Disposal</th>
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<tbody>
<tr>
<td>1</td>
<td>BEES 4.0</td>
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<td>Eco-Quantum</td>
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<td>Envest 2</td>
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<td>3</td>
<td>BREEMAM</td>
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<td>EcoEffect</td>
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<td>EcoProfile</td>
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<td>Environmental Status Model</td>
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<td>ESCALE</td>
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them also use data collected by the developer of the tool. Level 3 tools, environmental assessment frameworks, rely more on guidelines and questionnaires than on databases.

The possibility to edit the database varies among the building environmental assessment tools. Most of the tools do not mention if it is possible to add or edit data to the database. It is not possible to add data in the database in ATHENA™ or Eco-Quantum. In the case of Envest 2, the user can ask BRE to add data. BEAT (2002) allows the user to add, edit and delete data in the database.

The use of different databases and the possibility to add and edit data make the comparison very difficult. Due to different data sources and collection methods, the comparison of the environmental impact of materials is impossible (Trusty and Meil, 2002a,b). Furthermore, the comparison of the different research and the environmental assessment’s results is difficult, if not impossible. Environmental assessment tools are used by various users, who set different requirements for the data needed. The users need different kind of data to some extent, but different users do not necessarily need the data simultaneously (Kohler, 1999). If the tool is used by various users with different needs, the amount of required data may become too large, and some compromises have to be made. Furthermore, updating the data is challenging due to the development of tools, processes and products.

### 3.3.5. Forms of results used

The results of the environmental assessment of a building can be presented in forms of graphs, tables, grades, certificates, and reports. Graphs and tables are the most popular forms. Moreover, most of the building environmental assessment tools use different kinds of reports to present the results of the environmental assessment. Level 3 tools prefer reports more than Levels 1 and 2 tools. Only a few of the tools have grades and certificates. For example, BREEAM uses grades: pass, good, very good, excellent and LEED® uses grades silver, gold and platinum.

Instead of certificates and reports, consumers and some designers would prefer building product labels as they would facilitate decision making (Kohler, 1999). The producers of building products and components would welcome the labels with content. The problem is that the labelling system would not be consistent and up-to-date regarding all the materials and components used in a building (Kohler, 1999). Level 1 tools, for example BEES 32, are for product comparison and information sources. BEES includes actual environmental and economic performance data for 230 building products at the moment. BEES encourages the manufacturers of the building products to collaborate with them so that their products may be included in BEES in the future.

The problem may arise if the Level 1 tools are used in the decision making for the whole building design. Sometimes the tools might be overloaded (Trusty, 2000). As Kohler (1999) points out, in the real life cycle of a building product, the other products inside the whole buildings and the environment interact. In comparison, in the labelling approach, the focus on the whole building seems more realistic.

Whether the results are shown in graphs, tables or reports, they should be presented comprehensively for the whole building and for every phase of the life cycle of the whole building. This is necessary because the building environmental assessment tools cover the building’s life cycle differently. There is risk that incorrect assumptions and conclusions are made if the results from different tools are compared only at the

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### Table 5

<table>
<thead>
<tr>
<th>Database of the tools</th>
<th>ATHENA classification</th>
<th>Assessment tool</th>
<th>Database</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>BEES 4.0</td>
<td>Generic data and brand specific</td>
<td></td>
</tr>
<tr>
<td>TEAM™</td>
<td>DEAM Starter Kit</td>
<td>Athena Institute</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>ATHENA Institute</td>
<td>Collected by DBUR (Danish Building and Urban Research)</td>
<td></td>
</tr>
<tr>
<td>BeCost</td>
<td>Environmental profiles of building materials produced in Finland</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eco-Quantum</td>
<td>A compilation of a number of publicly available generic data sources such as BUWAL, APME and ETH and data from LCA’s conducted by IVAM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Envest 2</td>
<td>UK based data on service life, exposure factor, energy and water consumption benchmarks, LCA data for material and Ecopoints</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EQUER</td>
<td>Product data bases of Swiss and German origin, Oekoinventare (ETHZ) on building materials</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEGEP®</td>
<td>SIRADOS, ECOINVENT, GEMIS, the Baustoff Ökoinventare, and LEGEP database</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PAPOOSE</td>
<td>Green Guide</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BREEAM</td>
<td>Accompanied by a database for energy and materials</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EcoEffect</td>
<td>No database included</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EcoProfile</td>
<td>Name of the database not mentioned</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environmental Status Model</td>
<td>No database included</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ESCALE</td>
<td>No database included</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEED®</td>
<td>No database included (uses LEED® rating system and reference guide)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
whole building level. One tool may cover all the phases of the building’s life cycle while the other covers only a few phases. In addition to this, the former tool may have several criteria for every phase of the life cycle, while the latter has only a few. There is no point comparing the results from these two tools at the whole building level as it would not give realistic information.

Furthermore, the users of the tools should be able to trace the building materials, products and components which cause the biggest environmental loads in the whole building. Then the optimisation and the comparison between different solutions would be possible. It would be beneficial, if the tool could recommend “a better solution to replace the environmentally unfriendly solution”. But this would probably make the tool more complex. One has to remember; changing a building product in one place may cause changes elsewhere. Cole (1999) points out the different users of the tools might be interested in different aspects and issues. Also, the users have different skills and knowledge. This should be considered in the structure of the output of the results. The results of the tools should be interpreted unambiguously. The problem occurs when qualitative data and criteria are used, especially if any comparisons are made (Haapio and Viitaniemi, 2007). Comparisons may be done at different levels. Cole (1999) points out four types of “comparison”:

- comparing a specific performance criterion relative to a declared benchmark
- comparing performance scores of one criterion with the others within the same building
- comparing a specific performance criterion with the same criterion in another building
- comparing the overall performance profile with other buildings’ performance profiles.

What are the benefits of the reports and certificates, if the results by different tools cannot be compared? By choosing one tool, the user is forced to a certain model; e.g. definitions, weighting or scoring systems, and databases. And the comparison of the results with another tool’s results is difficult, if not impossible.

3.4. Uncertainties and errors

Almost always, the calculations, analyses and interpretations of the results include uncertainties, sometimes they even include errors. There are random errors and systematic errors. Normally, the former does not radically influence the results as positive and negative errors cancel each other out. The latter is more radical as they are caused by measuring tools or methods.

The building environmental assessment tools do not mention if they report the uncertainties or the margin of an error in the results. However, none of the tools were tested for this study. This study focuses on written material evaluated by the authors. Uncertainties and errors may occur in different phases of the environmental assessment of the building. There might be errors in the values in the beginning; in the database. The possibility of error increases if the database can be edited. Also, the collection method of the data has an influence on the possibility of an error. The development of the processes and the products is rapid, and therefore their environmental impacts change. This sets high requirements for the updating of the database. However, an error in the database can multiply the error in the calculations and the results.

There is a possibility that the building environmental assessment tools include errors in their definitions and calculations, which affect the results. These errors are very difficult to discover. Furthermore, the interpretation of the results is an obvious place for the uncertainties and errors. Cole (1999) points out that the interpretation of the results can vary considerably depending on the assessor. Different building environmental assessment tools use different units. This may mislead the users of the tools. When measuring the amount of something, for example waste, the results give a different picture depending on the used unit; concrete construction waste has high mass and low volume compared to wood waste (Trusty and Meil, 2002a,b). An example given by Haapio and Viitaniemi (2007) was the volume of 1000 kg of concrete construction waste is ∼0.4 m³. On the other hand, 10 m³ of wood construction waste is ∼5300 kg in weight, and 10 m³ of concrete construction waste is ∼24 000 kg in weight. From the viewpoint of image, wood construction waste benefits from expressing the amount of waste in unit of mass (kg), and concrete construction waste benefits from using the unit of volume (m³) (Haapio and Viitaniemi, 2007).

As another example, the results presented per surface area (m²) do not always tell the whole truth. The volume (m³) should also be considered, because the height of the spaces may vary (Junnila, 2004). The surface area (m²) of the building can be measured from the outside (including the walls) or from the inside (excluding the walls). How the measurements are taken has a great influence on the results. For example, energy consumption is often expressed as giga joules per unit area of
Building environmental assessment tools vary to a great extent. The tools have been developed for different needs and purposes. The tools can be used to assess building products and buildings; existing buildings, new buildings, and buildings under refurbishment. The tools can assess different types of buildings: residential buildings (single family and multi-unit), office buildings, and other types of buildings. Some of the tools are suitable for assessing the whole range, whereas some of the tools can only be used for assessing new buildings or office buildings. The tools cover the life cycle of a building differently, they rely on different guidelines and databases. The tools hand out different labels and certificates. Moreover, different cultural factors and various regulations in different countries complicate the situation even further. Building environmental assessment tools are not all commensurable. The comparison of the tools and their results is difficult, if not impossible. The use of tools is not obvious; where and when they should be used, who should use them, and how the results from the assessment should be utilised. Most probably, these issues have reduced the use and utilisation of the building environmental assessment tools.

How should the users know which building environmental assessment tool is suitable for a certain building? And which tool gives the most reliable results? The tools do not mention if they report the uncertainties, or the margin of error, in the results. Consequently, the user of the tool is not necessarily able to estimate the reliability of the results. Yet, this feature is essential. Who is responsible for the results if they include major errors? On the other hand, the user may choose the tool based on the results — which results suit best for their purpose. If one tool gives better results for a certain type of building than the other tools, there is a risk that users start promoting the tool in question. If the users’ selection criteria are based on the desired results, the reliability of the assessments has vanished.

The reusability of the building products should be taken into account and discussed more openly within the environmental assessment of buildings. The products can be reused elsewhere, or after their primary purpose of use, they may be recycled and used as raw material for new products. Sato et al. (2005) introduce life cycle resource (LCR) and life cycle waste (LCW) indices for assessing resource sustainability into LCA for buildings. As an example, after their service life, used wooden building products can be used as raw material for another product (e.g. chip boards), or as energy source substituting non-renewable energy resources. Reuse, recycling and substitution are topics which need further research.

Building environmental assessment tools often the use predicted service life of a building in the assessments. The length of the service life is taken as given without further analysis. And yet, a building may comprise over 60 basic materials and ~2000 separate products, all with different service lives (Kohler and Moffatt, 2003). The service life of the inaccessible parts of the building should be the same as the service life of the building, but the service life of accessible parts may be shorter (ISO, 2000). When the service life of the accessible parts is shorter, they need maintenance or refurbishment during the service life of the building. Maintenance and refurbishment have environmental impact. How the service lives of the products and building affect the results of the environmental assessment, should be analysed thoroughly.

A partly neglected aspect is the utilisation of the results of the building’s environmental assessment. The need for a user survey is obvious. The factors influencing the choice of the tool need to be revealed. The utilisation of the results should be studied; could it be more efficient? The key question is; how the tool and its results have affected the decision making? To be able to critically analyse the benefit of the tools, these issues need further clarification. The development of the tools would also benefit from it. Furthermore, it would be beneficial to carry out research on what kinds of buildings are assessed, and compare the quality of assessed buildings to the existing building stock. There is a risk that “low quality buildings” will not be assessed
at all when the assessment is not mandatory. Only “high quality buildings” will be assessed, knowing that they will succeed in the assessment (e.g. get level A points or certificate platinum). In addition, when we speak about “high quality buildings”, what do we actually mean by that? Are we talking about buildings that meet the requirements of the current building regulations? There is a possibility that the building environmental assessment becomes mandatory. The mandatory requirements would mean that all the buildings should be assessed, not just the buildings known as “high quality buildings”. A standardised framework or scale for the existing building stock would probably clarify the current situation, and make it easier to analyse and compare new designs and buildings. The knowledge gathered from user experience should be utilised in the development of the tools. Furthermore, the standardisation work could benefit from it.

5. Conclusion

Since the field of building environmental assessment tools is vast, the aim of this study is to clarify that field by analysing and categorising the existing tools. The comparison of the tools and their results is difficult, if not impossible. For example, the tools are designed for assessing different types of buildings, they emphasise different phases of the life cycle, and they rely on different databases, guidelines and questionnaires.

There is an obvious need for a user survey. The factors influencing the choice of the tool need to be revealed. The key questions are: how do the results of the tools could be used more efficiently, how do the tools and their results have affected decision making? To be able to critically analyse the benefit of the tools, these issues need to be clarified. The development of the tools would also benefit from it. Furthermore, building environmental assessment tools often use the predicted service life of a building in the assessments. However, it is taken as given without further analysis. How the service lives of the products and the buildings affect the results of the environmental assessment, should be analysed thoroughly.

In addition to the environmental aspect, sustainable building includes the economic and social aspects. A vision of transforming the existing building environmental assessment tools into sustainability assessment tools seems, at the moment, far away. However, future requirements are challenging for the tools. One wonders what the world would be like if all the new buildings were “sustainable buildings” according to the current image of the building environmental assessment tools.

Is it possible that “the high quality building” of today will be “the low quality building” of the future?

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